September ε Perseids observed by the Czech Fireball Network in 2013, 2015, 2016, and 2017

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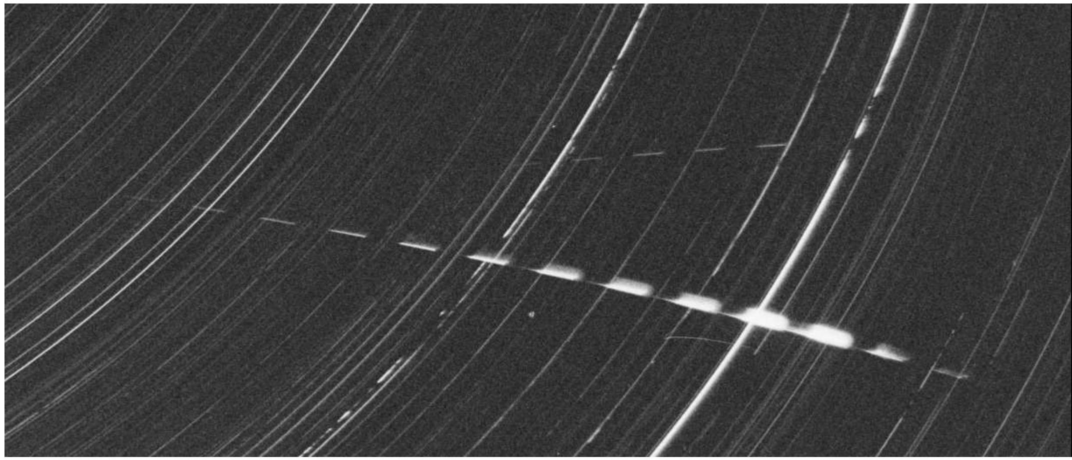
Instrumentation

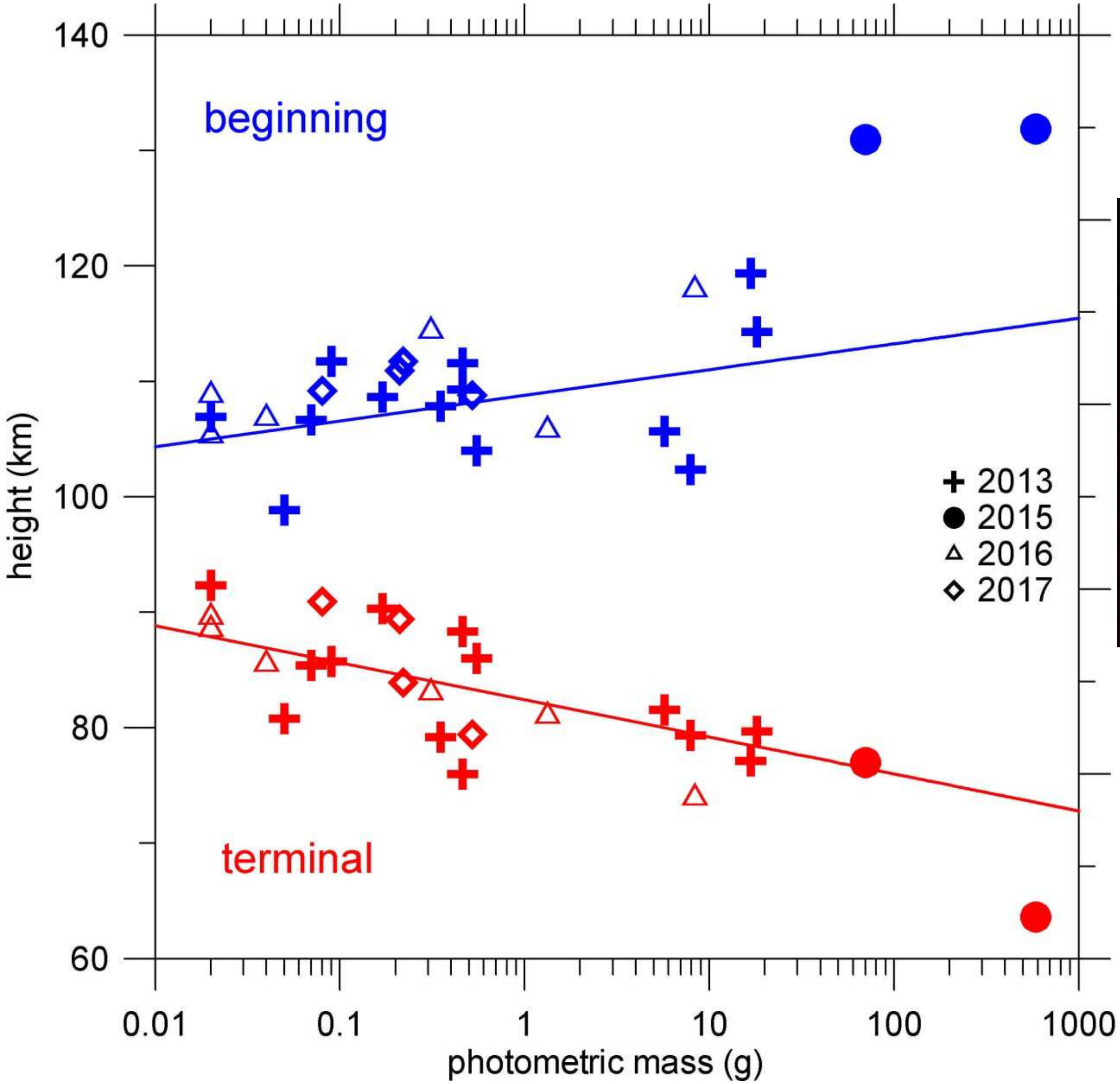
- 2013 – Autonomous Fireball Observatories (AFO)
  large-format sheet film all-sky cameras, brightness detectors (BD) with 5000 samples/s (Spurný et al., 2007), long-focus cam.
  - – one Digital AFO (DAFO)
- 201x – DAFOs: digital all-sky cameras with BD
  - – DFK 31AU03 video: 600 grooves/mm, 7.5 fps




#208 SPE fireball activity

- 2013
  - 13 multi-station fireballs
  - 19 radiometric records on 9 Sep from 21:53 to 23:44 UT (fireball maximum at 22:13 ± 4 min UT)
  - has to be from one revolution trail of long-period comet (Lyytinen and Jenniskens 2003, Rendtel at al. 2014)
- 2015
  - 2 very bright fireballs with persistant trains
- 2016
  - 6 fireballs, one cluster of meteors (Koten et al. 2017)
- 2017
  - 4 relatively short fireballs

Atmospheric trajectories

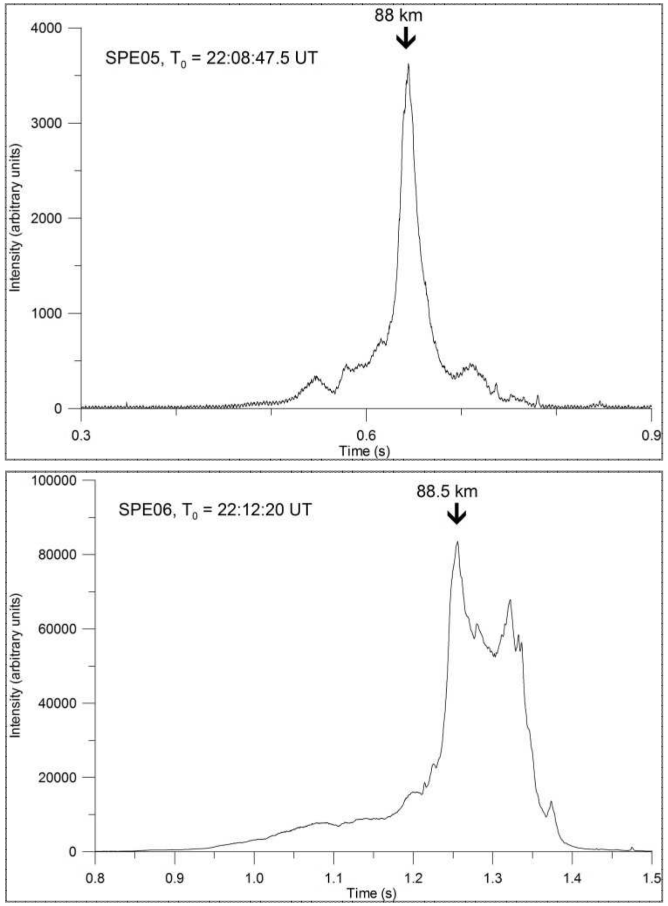


EN180915 (DAFO)

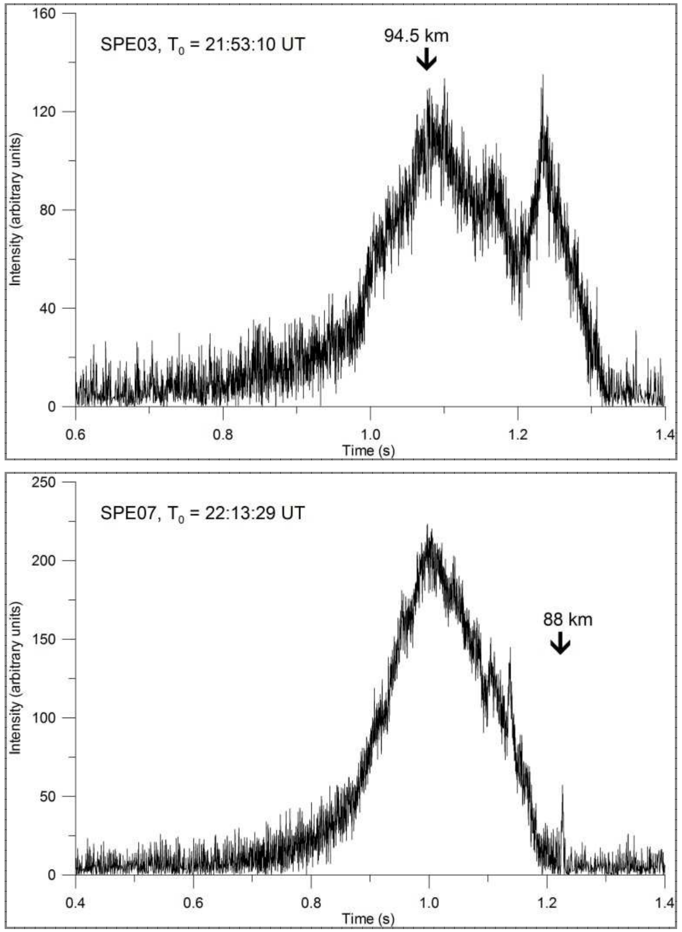
Light curves

Two types of light curves were observed among the 2013 outburst fireballs and also SPE firebals in years 2015-2017

● with expressive flare (PE type IIIA)

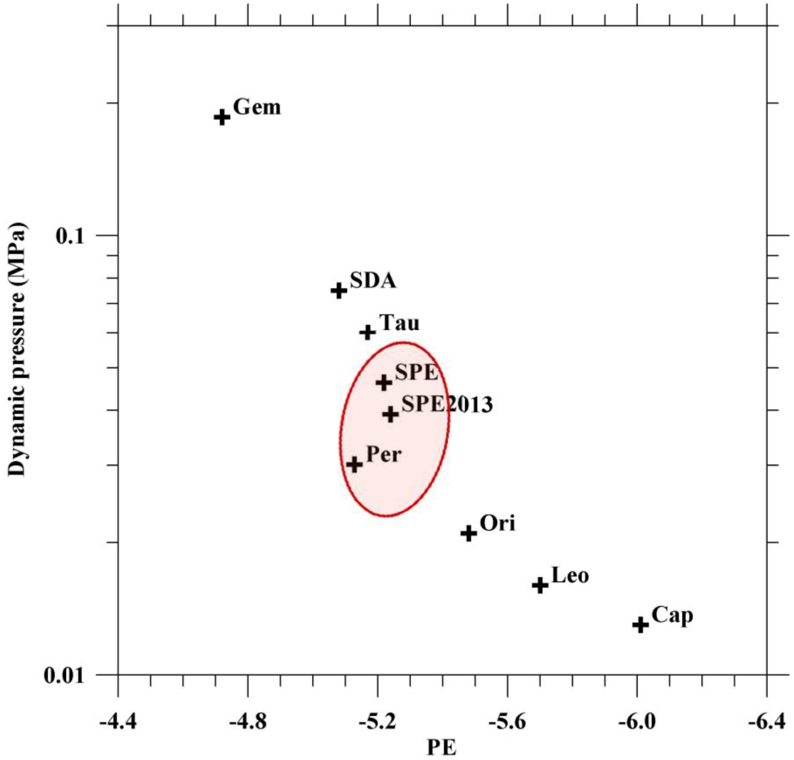


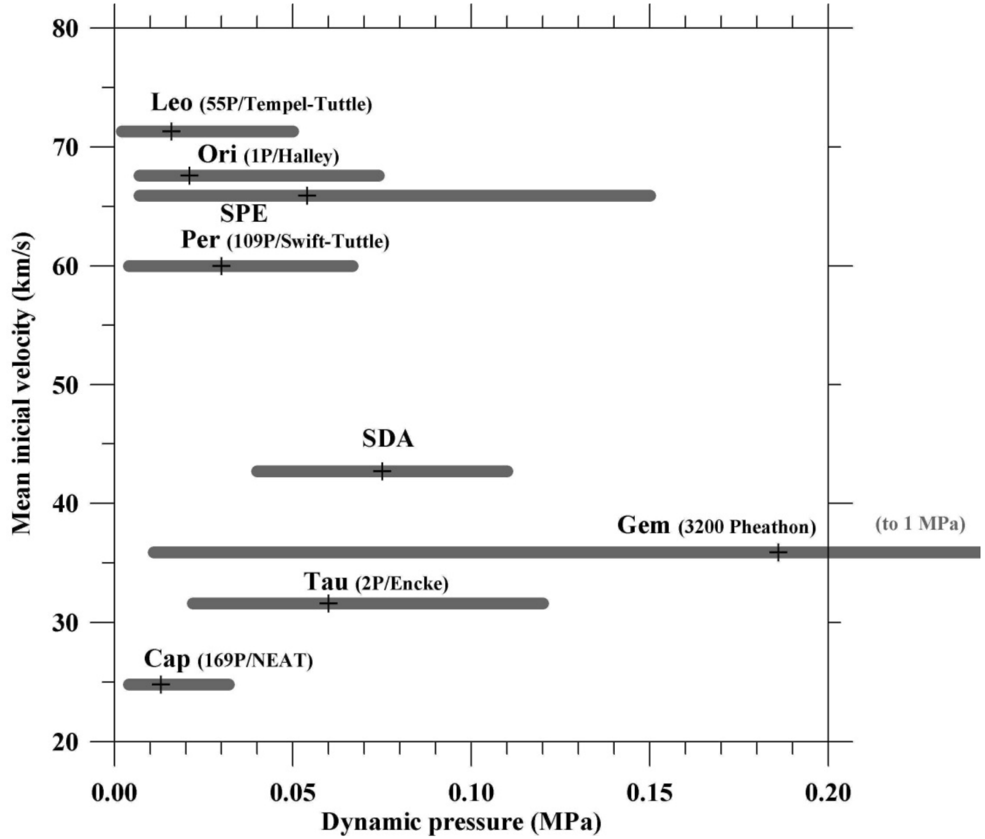
● without expressive flares (type II/IIIA)



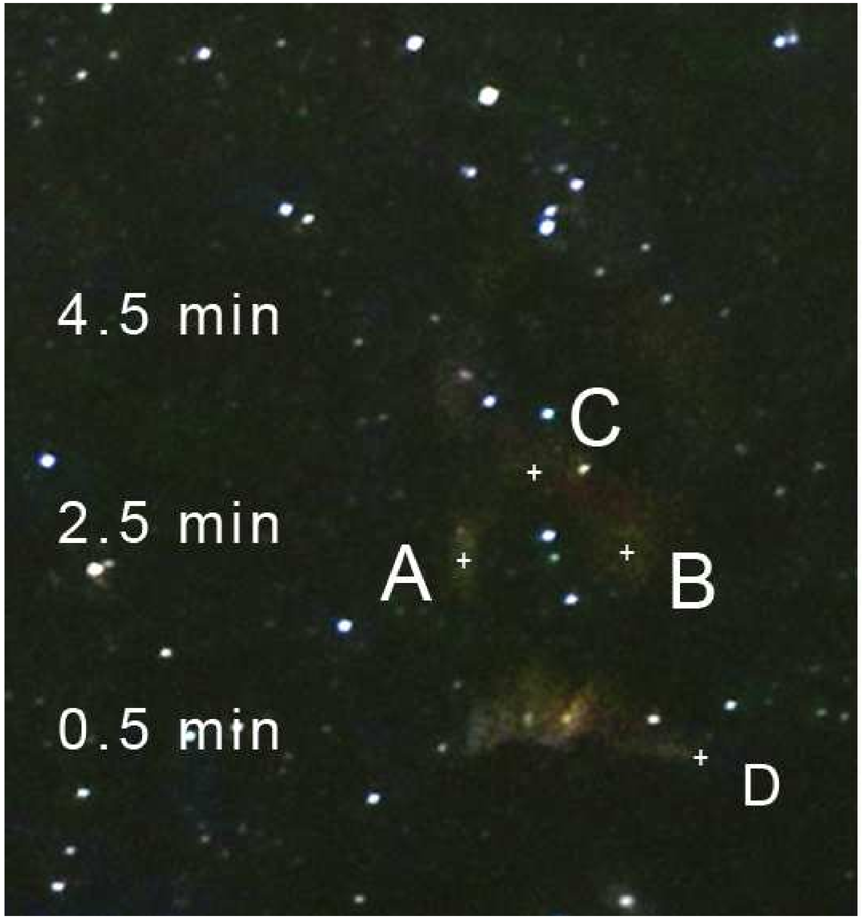
Dynamic pressure *p* and PE

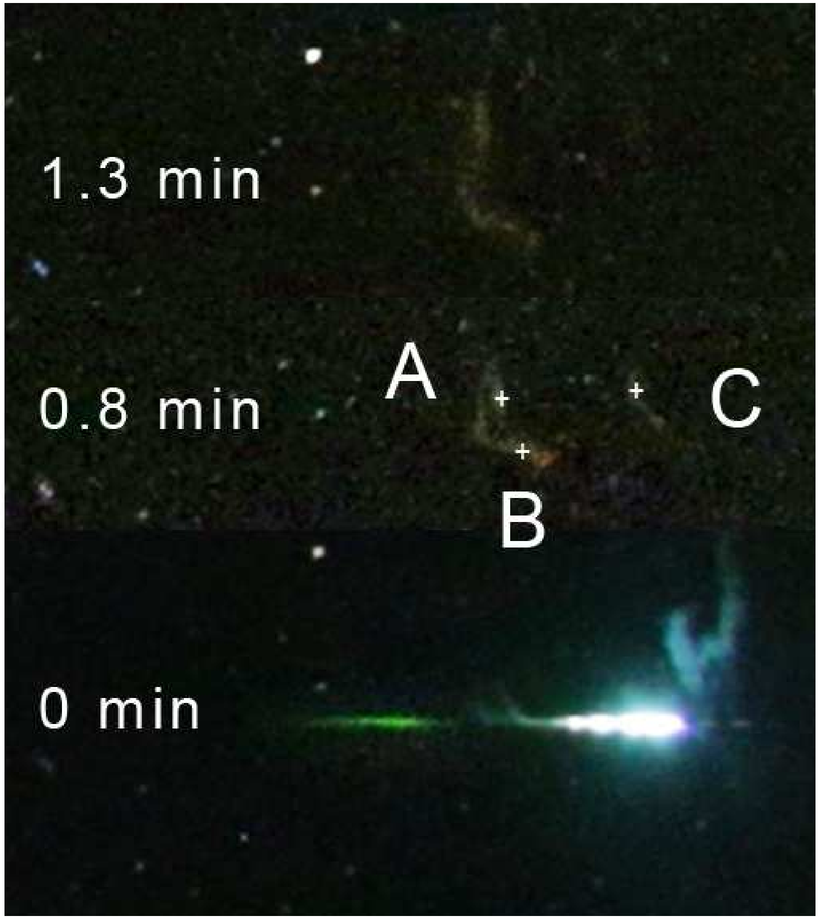
- *p* depends on height and velocity just before the fragmentation, which is associated with flares (Borovička 2006). Accuracy of determination of flare heights is better than 1 km
- SPE are similar to Perseids
- mean p_{2013} = 0.04 ± 0.03 MPa
- mean p = 0.05 ± 0.03 MPa





Persistant trains

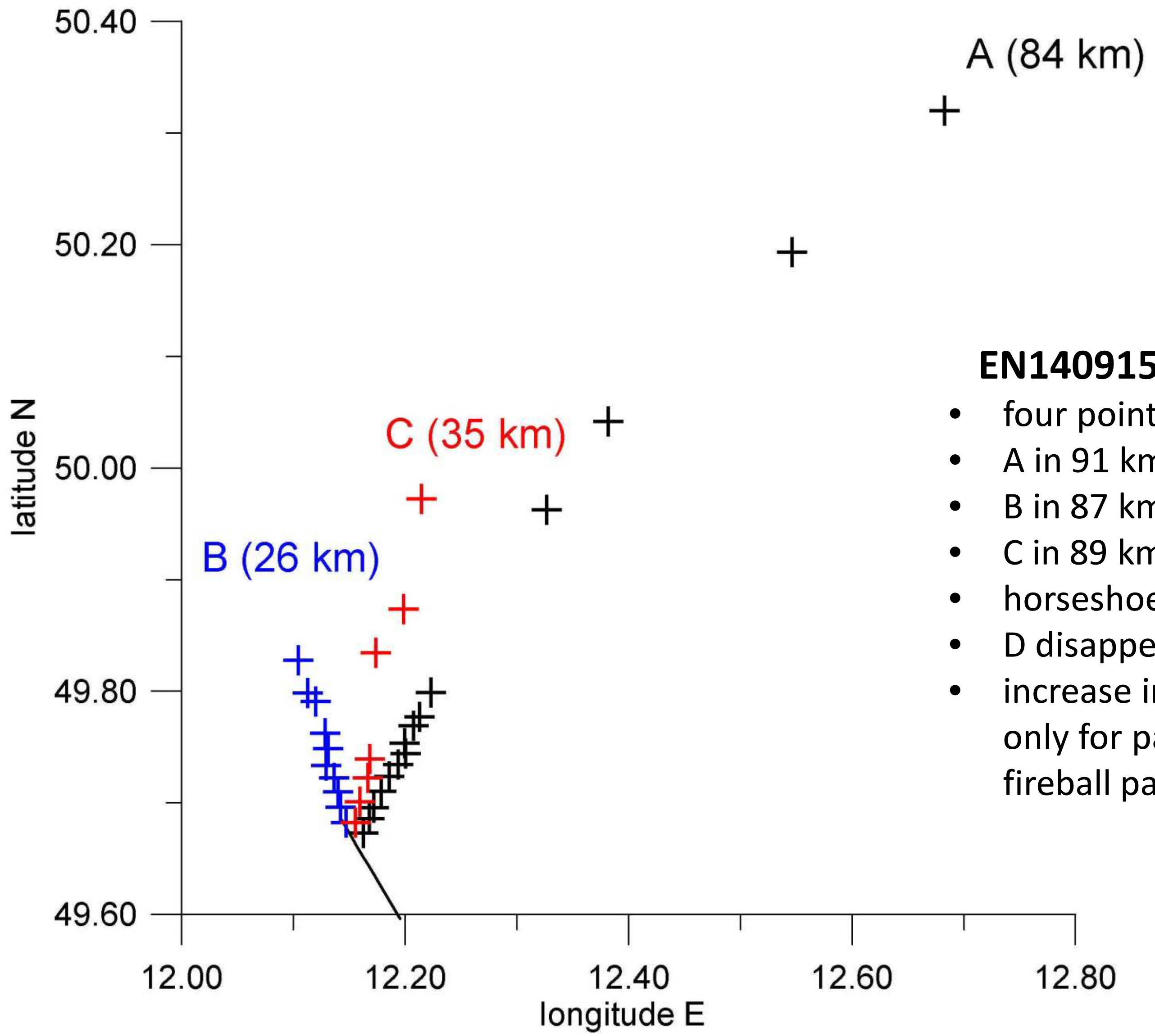




EN140915 – multi-station for 34 min
(-13.2mag, 70g, IIIB)

EN190815 – less than 3.5 min
(-15.2mag, 580g, IIIA)

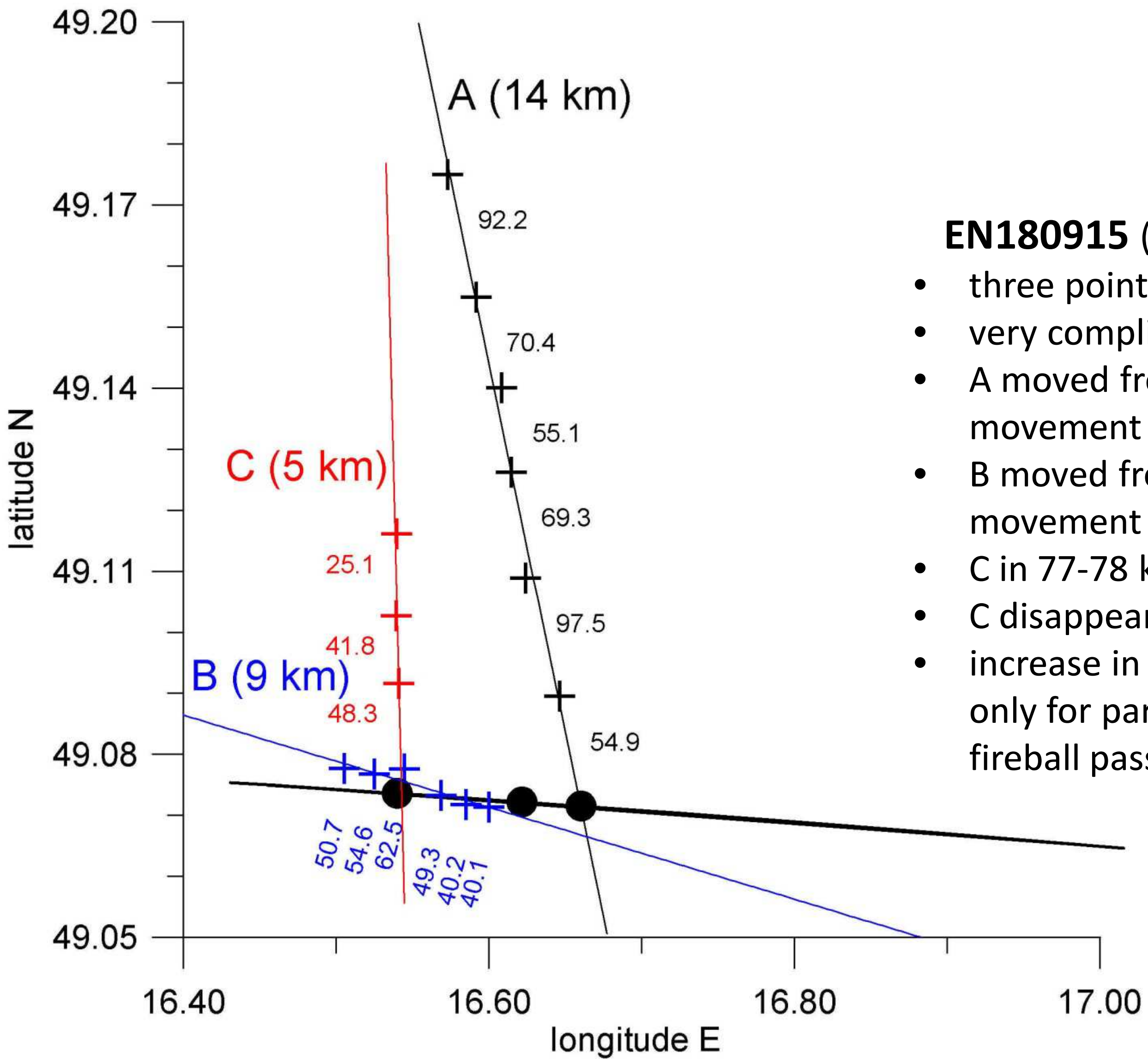
Persistant trains



EN140915 (duration > 40 min)

- four points in heights 79 – 91 km
- A in 91 km, movement 60 m/s
- B in 87 km, movement 50 m/s
- C in 89 km, movement 65 m/s
- horseshoe-like shape first 9 min (B and C)
- D disappeared after 1 min (86-79)
- increase in train brightness observed only for part A: 1, 8 and 11 min after the fireball passage

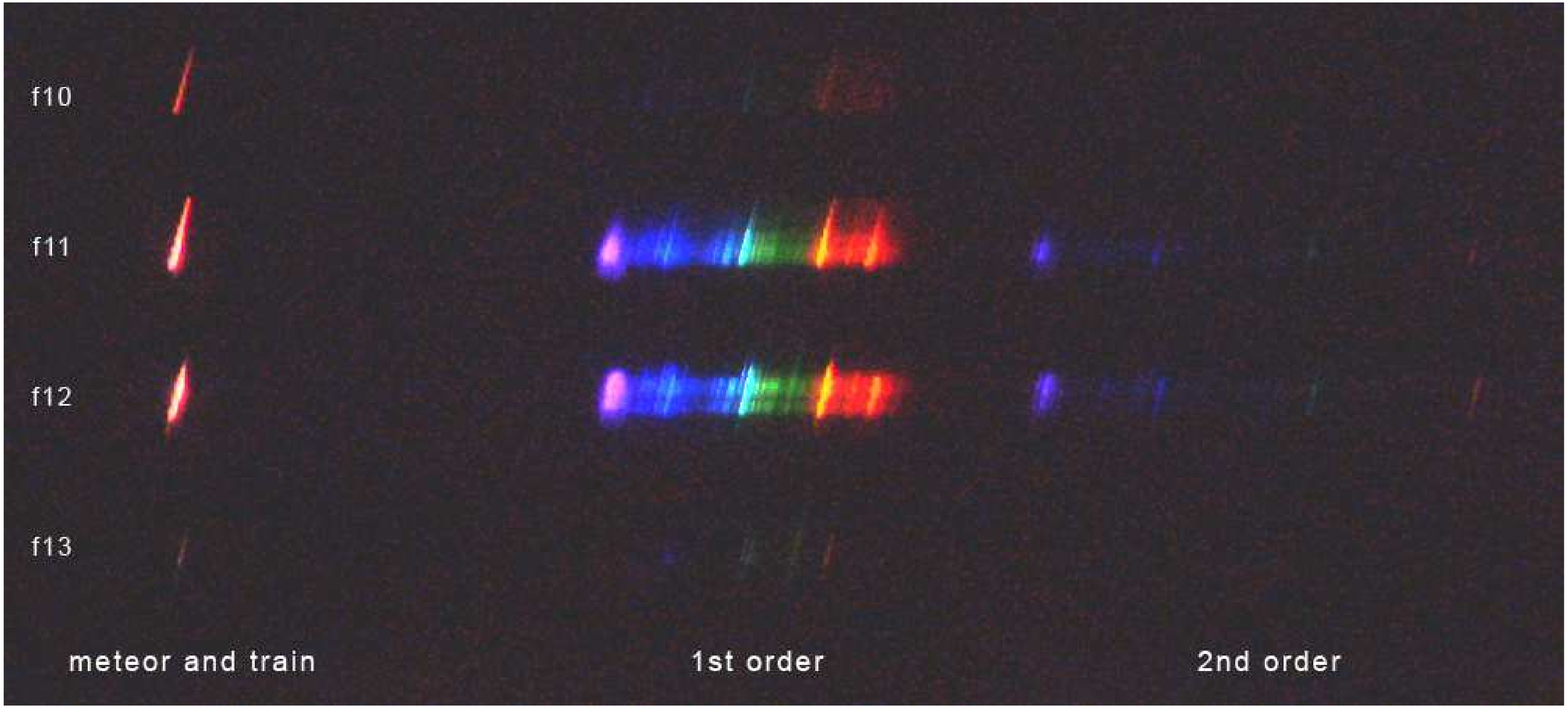
Persistant trains



EN180915 (duration 5 min)

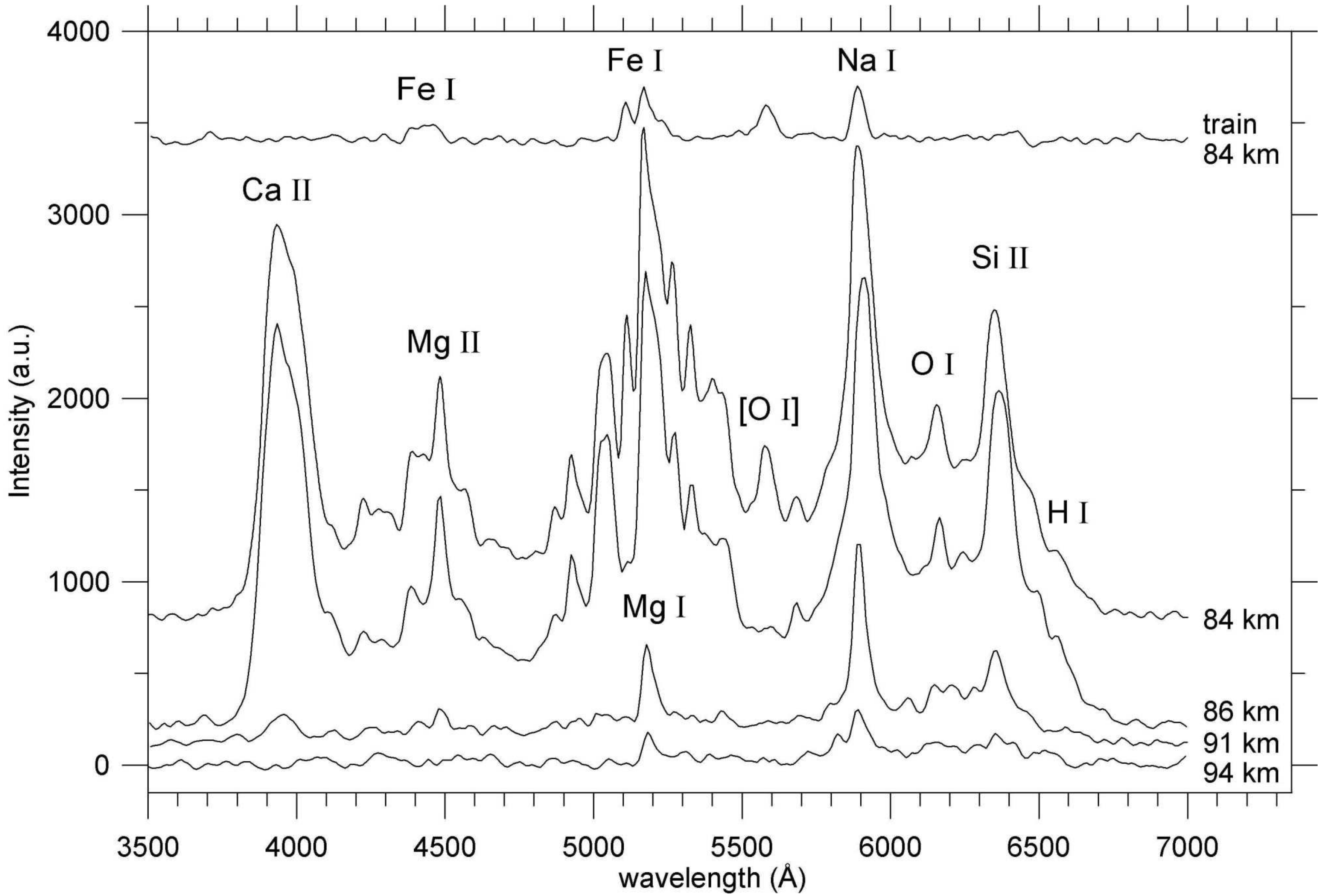
- three points in heights 77 – 93 km
- very complicated shape
- A moved from 93 down to 90 km, movement 70 m/s
- B moved from 88 up to 91 km, movement 50 m/s
- C in 77-78 km, movement 40 m/s
- C disappeared after 2 min
- increase in train brightness observed only for part B: 3.5 min after the fireball passage (height 91 km)

Spectrum of EN140915



CCD camera DFK 31AU03 (1024x768 pix, 7.5 fps, 8 bit) with blazed grating (600 grooves/mm).
Spectrum of the fireball in 4 frames, spectrum of the train in 2 frames, 4 frames measured.
Calibrated by 5 lines (Na I, Mg I, Ca II, Mg II, Si II). Resolution of the first order 14 Å/pix.

Spectrum of EN140915



Spectrum of EN140915

Two spectral components observed (Borovička, 1994), 28 lines identified

Main spectrum (4000 K)

- observed above 94 km

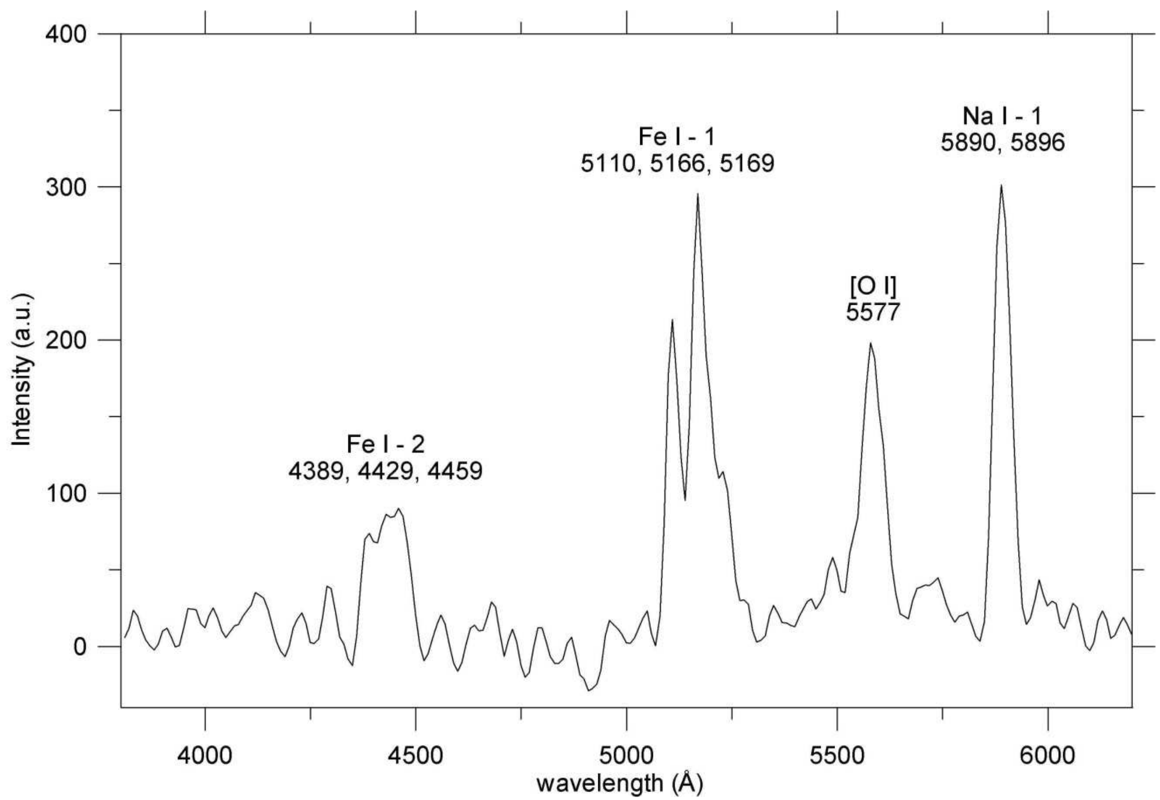
Second spectrum (10000 K)

- appeared between 93 - 90 km (Si II – 2 in 93 km, Mg II – 4 in 92 km, Ca II – 1 in 90 km)
- Borovička et al. (2006) – second spectral component is connected with a meteor shock wave, which is created at the time when the mean free path (MFP) is smaller than the meteoroid size (free molecular flow changes into continuous flow)
- Popová (2005) – transition between the flow regimes for meteoroid of 1.5 cm radius and velocity of 70 km/s is between 90 and 93 km (reflected and evaporated molecules were taken into account for MFP computation)
- Bronshten (1983) – we performed the same computation process for parameters of EN140915 – the height of the beginning of the continuous flow regime depends on the method of determination of MFP
    - Maxwell-Boltzmann distribution of velocities of identical particles with size of N_2 $2.2\ 10^{-10}$ m (Sutton, 1965), which leads to the height of 90 km
    - MFP defined by the dynamic viscosity of gas (Dixon, 2007) leads to 97 km
- H I – 1 (656.3 nm) appeared around 90 km, may indicate the presence of organic matter or water bound in meteoroid minerals (Borovička, 2000; Jenniskens & Mandell, 2004)

Spectrum of EN140915

Spectrum of the train

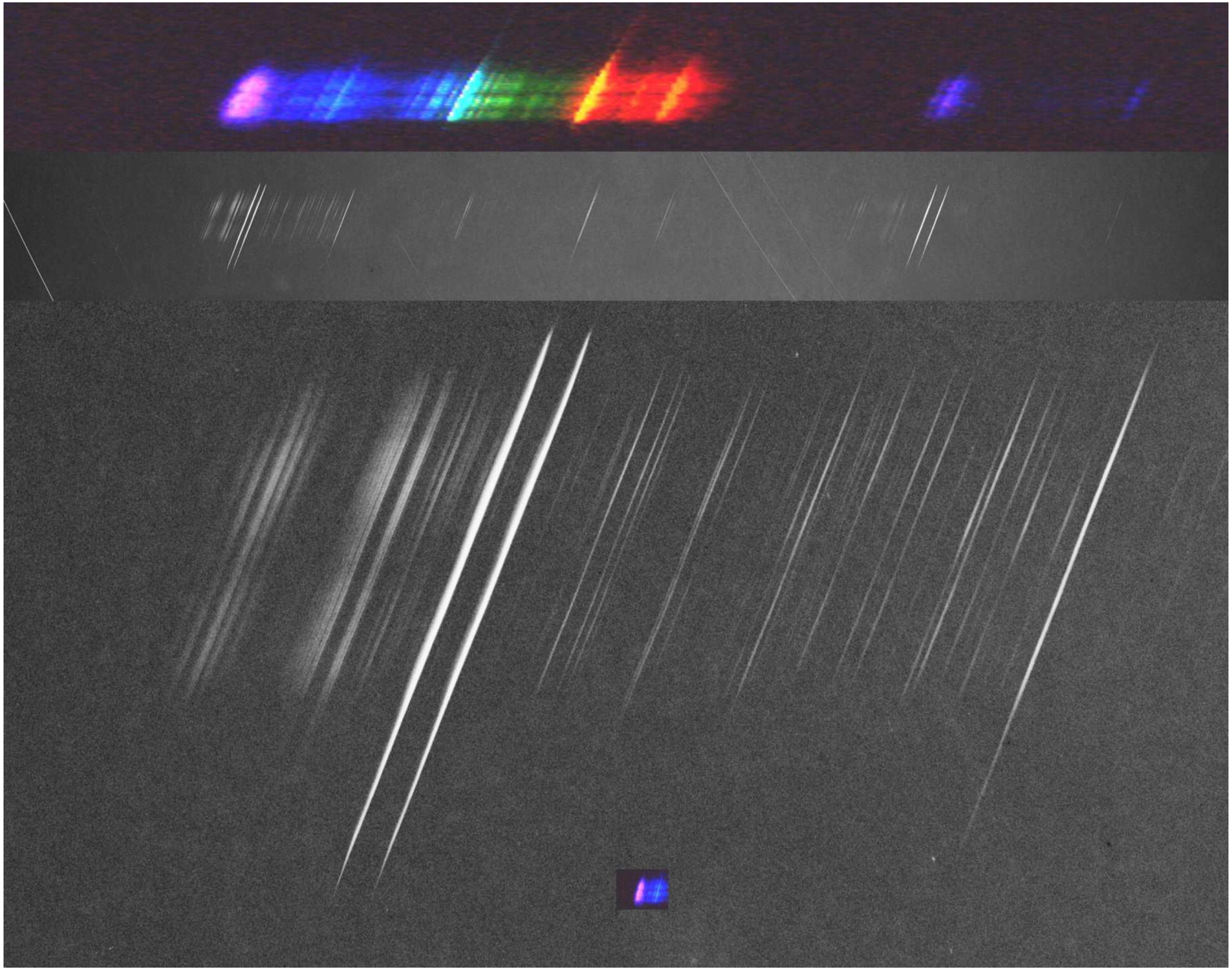
- in the height of 84 km, 7 lines identified (Fe I – 2 at 438, 443 and 446 nm, Fe I – 1 at 511 and 517 nm, [O I] at 557.7 nm, Na I – 1 at 589 nm)
- presence of Fe I – 1 lines and absence of Mg I – 2 at 517 nm corresponds to the emission lines of the afterglow phase (Borovička and Jenniskens, 2000; Borovička, 2006)



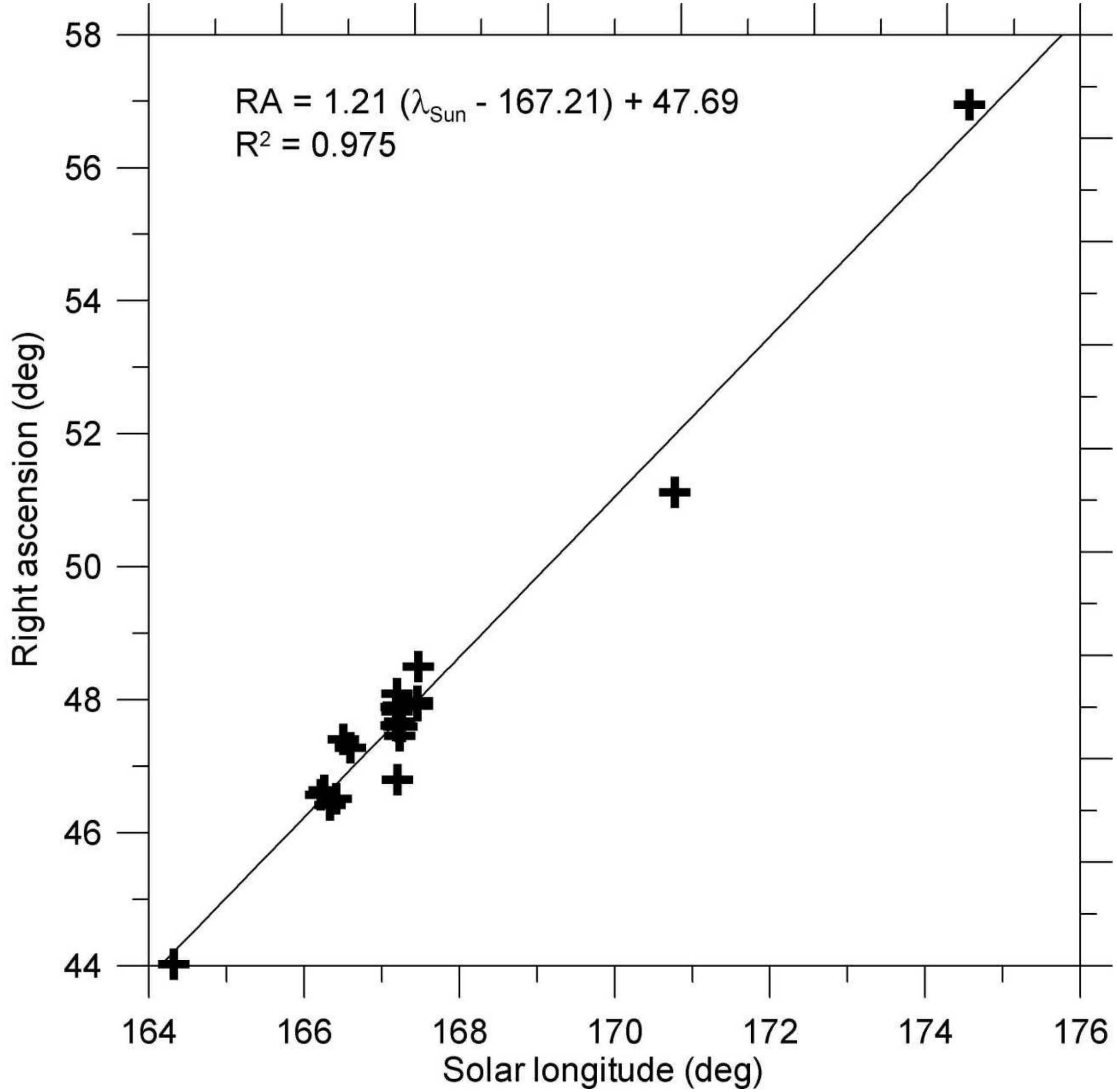
Spectrum of EN090916

Spectral photographic camera with blazed grating (600 grooves/mm).
(-11.6mag, 8 g, type II/IIIA)

Spectrum of EN090916

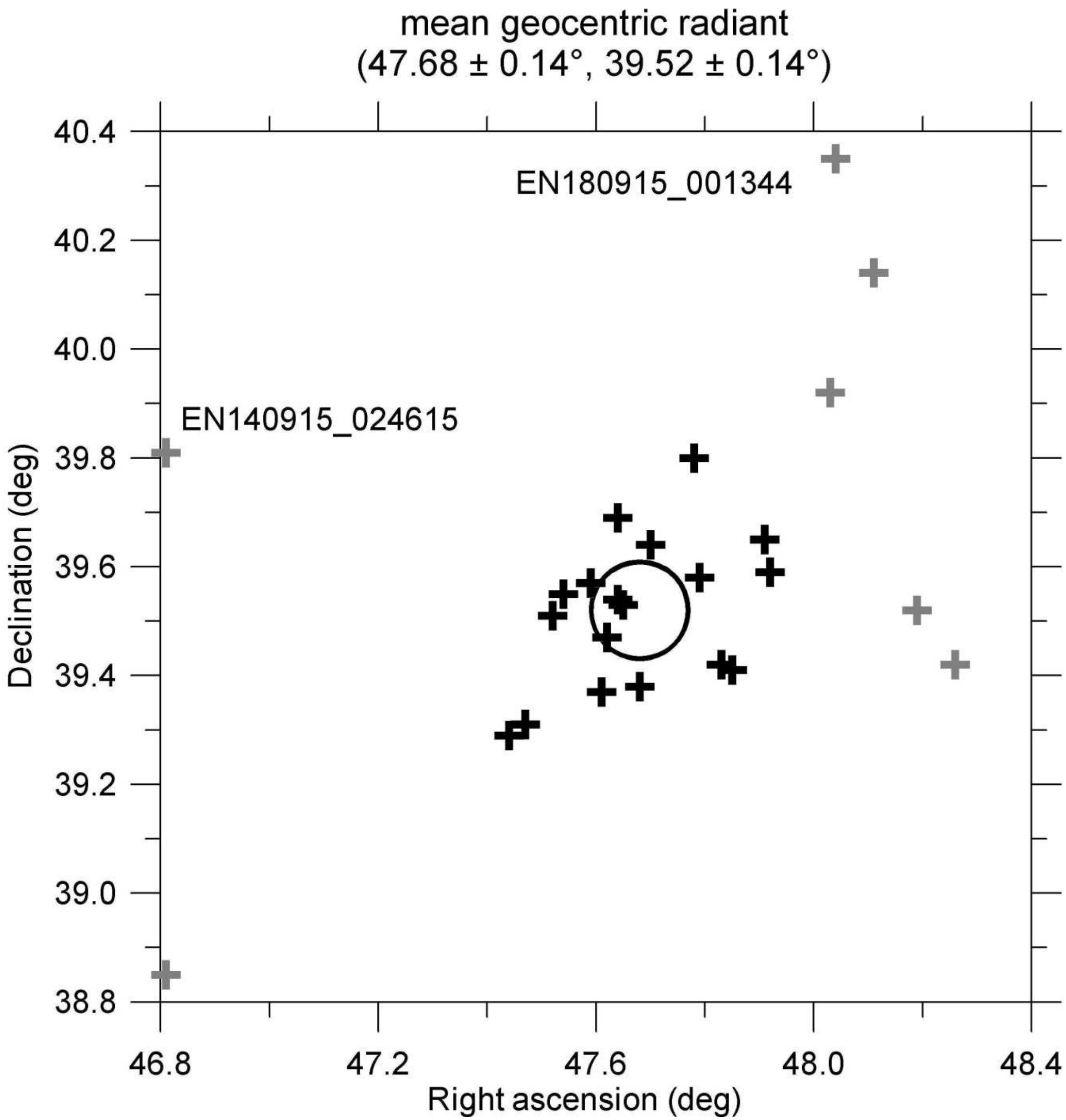


Radiant and orbit



geocentric radiant

Radiant and orbit



Radiant and orbit (2013)

- mean geocentric radiant determined from six most accurate fireballs of the 2013 SPE outburst for $\lambda_{\odot}$ = 167.21 deg

  R.A. = 47.69 ± 0.12 deg

  Dec. = 39.51 ± 0.10 deg

  v_G = 64.81 ± 0.14 km/s
- mean orbit determined from six most accurate fireballs

  v_{inf} = 65.93 ± 0.15 km/s

  e = 0.989 ± 0.009

  q = 0.723 ± 0.003 AU

  i = 139.3 ± 0.2 deg

  ω = 244.3 ± 0.2 deg
- long-period comet as a parent body of the shower

  a ≈ 66 AU (P ≈ 530 yr)

Orbit

Dynamicaly the best fireballs (v_{inf}, e, q, i)

- 2015

  EN140915_024615 (65.86, 0.991, 0.6905, 141.30)

  EN180915_001344 (66.43, 0.999, 0.7216, 141.39)

- 2016

  EN090916_230659 (65.97, 0.990, 0.721, 139.73)

- 2017

  EN080917_234345 (65.94, 0.995, 0.730, 138.94)

Mean orbits (v_{inf}, e, q, i)

- SPE 2013 (this work)

  (65.93, 0.989, 0.723, 139.3) (P ≈ 530 yr)

- IAU MDC dráha (Gajdoš and Porubčan, 2005)

  (66.6, 1.016, 0.734, 140.6)

- SPE 2013 (Gajdoš et al, 2014)

  (65.3, 0.96, 0.714, 139) (P ≈ 75 yr)

- SPE 2013 (Madiedo et al, 2018)

  (65.9, 0.979, 0.723, 139.15) (P ≈ 200 yr)

Conclusions

- SPE2013 maximum fireball activity at 22:13 ± 4 min UT and corresponds to the maximum of video meteors (Rendtel et al. 2014 , Gajdoš et al. 2014)
- on the basis of atmospheric trajectories, ablation abilities, and dynamic pressures material is of cometary origin and is a bit harder than that of Orionids and statistically the same as that of Perseids
- on the basis of orbits the parent body is long-period comet
- persistant train is observed for the longest time in 91 km
- beginning of meteor shock wave between 90 – 93 km from spectral records
- beginning of meteor shock wave between 90 – 97 km from theory
- high-altitude wind has mean values 40 – 70 m/s in heights 77 - 93 km
- spectrum is similar to spectra of other shower meteors with similar velocity and brightness and does not show any exceptional or rare features
- the geocentric radiant of the 2013 SPE outburst for solar longitude 167.21° is 47.69 ± 0.12°, 39.51 ± 0.10° and can be used for confirmation of future outbursts (in 2026 and 2030) predicted by Rendtel et al. 2014